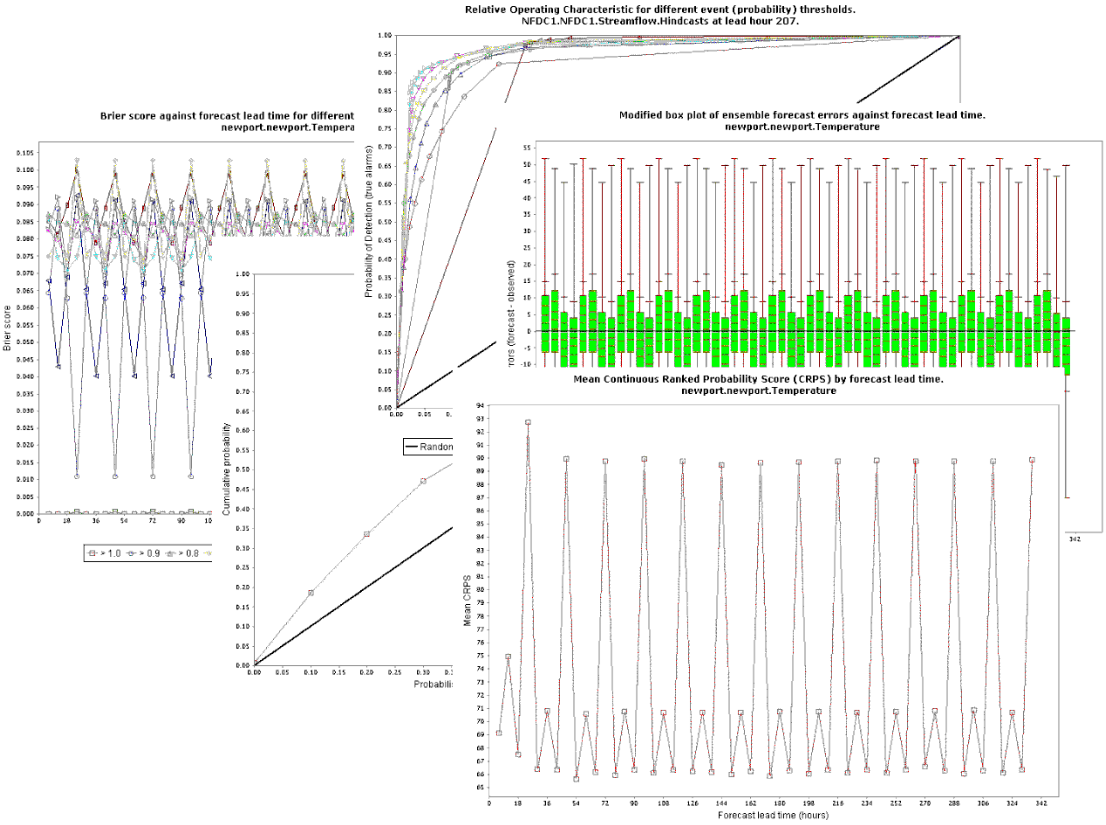
Ensemble Verification System (EVS)

Version 4.0



Installation and release notes

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Preface

The Ensemble Verification System (EVS) is a Java-based software tool developed by the Hydrological Ensemble Prediction (HEP) group of the US National Weather Service's Office of Hydrologic Development (OHD). It is designed to verify ensemble forecasts of hydrologic and hydrometeorological variables, such as temperature, precipitation, streamflow and river stage. The EVS is intended to be flexible, modular and open to accommodate enhancements and additions, not only by its developers but also by its users. As such, we welcome your participation in the continuing development of the EVS toward a versatile and standardized tool for ensemble verification.

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Contents

1. *Installation instructions*

1.1 Contents of the full distribution

Currently, the full distribution of the EVS can be downloaded from:

http://www.nws.noaa.gov/oh/evs.html

The full distribution comprises (** are required to run the EVS):

Item	Description
EVS.jar**	The main executable and associated libraries
EVS_4.0_MANUAL.pdf	This manual
EVS_4.0_RELEASE_NOTES.pdf	The release notes, including changes and bug-fixes
EVS_4.0_TEST_DATA.zip	An example dataset for running the EVS
/reporting	Contains a template to report bugs or suggested enhancements
EVS_4.0_SOURCE.zip	A directory containing the Java source-code for the EVS
/javadoc	A directory containing "Javadoc" source code documentation
evs/resources/rscripts/	A series of scripts for generating custom verification plots in R
evs/resources/statsexplained/	Html guides to particular metrics available in the EVS.
EVS.bat	Example Windows batch file and command to use more RAM

1.2 Requirements

No formal installation of the EVS is required. However, in order to run the EVS you will need:

1. The Java^{TM} Runtime Environment (JRE) version 6.0 (1.6) or higher. You can check your current version of Java by opening a command prompt and typing java –version. If the command is not recognized, you do not have a version of the JRE installed. If the installed version is older than 1.6, you should update the JRE. The JRE is free software and may be downloaded from the Sun website:

   http://java.sun.com/javase/downloads/index.jsp

2. The EVS executable, `EVS.jar`, and associated resources in `EVS_4.0.zip`;
3. Microsoft Windows (98/2000/NT/XP/Vista/7) or Linux Operating System (OS). In addition, you will need:

   – A minimum of 256MB of Random-Access Memory (RAM) and ~50MB of hard-disk space free (not including the associated datasets).
   – For many applications of the EVS, involving verification of large datasets more RAM and disk space will be required. A minimum of 1GB of RAM and 2GB of disk space is recommended (see *Section 2.7*).

1.3 Unpacking and running the EVS

Once you have obtained the EVS software, unpack the zipped archive to any directory of your computer (e.g. `C:/Program Files/EVS_4.0/`) using, for example, WinZip^{TM} on Windows or the `unzip` command in Linux/Unix:

```
unzip EVS_4.0.zip
```

There are two possible ways of running the EVS, namely: 1) by executing the Graphical User Interface (GUI); and 2) by executing the EVS from the command line with a pre-defined project file.

Executing the EVS with the GUI:

Once you have unpacked the software, you may run the EVS by double-clicking on “EVS.jar” in Windows or by opening a command prompt, navigating to the root directory, and typing a java command that references the EVS jar file, such as:

```
java –jar EVS.jar.
```

Executing the EVS without the GUI:

In order to execute the EVS without the GUI, you must have one or more pre-defined EVS projects available. The EVS projects are specified in XML (see *Appendix A2*) and may be created with or without the GUI. For example, a base project may be created with the GUI and then altered manually or with a script outside of the GUI (e.g. changing the input and output data sources). One or more EVS projects may be invoked from a command prompt by typing a java command with the paths to the project(s) listed afterwards, for example:

```
java –jar EVS.jar project_1.evs
```

where `project_1.evs` is an EVS project (the project need not be located in the root directory, but should be referenced by its full path otherwise). By default, the graphical and numerical results are written to the output directories specified in the projects.

1.4 Troubleshooting the installation

<u>List of typical problems and actions:</u>

– **“Nothing happens when executing EVS.jar”**

Ensure that the Java Runtime Environment (JRE) is installed on your machine and is in your PATH. The JRE should be version 6.0 (1.6) or higher. To check that a suitable version of the JRE is installed and in your PATH, open a command prompt and type:

```
java -version
```

If the command is not recognized, the JRE is not installed and in your PATH. If the version is below 6.0 (1.6), update the JRE (see above).

If this does not help, check the root directory of your installation for a log file named `evs.log`. Send the error message to the authors for advice on how to proceed (James.D.Brown@noaa.gov).

– **“An error message is thrown when executing EVS.jar”**

If an error message is thrown by the JRE (i.e. a java error appears in the message), the error may be caused by the local installation of Java.

1.5 Altering memory settings

By default, the amount of RAM memory available to the EVS is restricted by the Java Virtual Machine. In order to perform ensemble verification with large datasets, it may be necessary to change this default and increase the amount of memory available. This is achieved by executing the EVS on the command line, whether invoking the GUI or running a project without the GUI. To execute the GUI with altered memory settings, navigate to the installation directory of the EVS, and type:

```
java –Xmx1000m –jar EVS.jar
```

where **`1000`** is the maximum amount of memory (in megabytes) allocated to the EVS in this example. The maximum memory allocation should be significantly lower than the total amount of RAM available on your machine, as other programs, including the OS, will require memory to run. For example, on a 32-bit Windows OS with 4000 megabtyes of memory, around 1200 megabytes of memory will typically be available for the EVS. The EVS will only start with an increased memory setting if the Java Virtual Machine can actually allocate the desired amount of memory.

1.6 Source code and documentation

The Java source code for the EVS can be found in the `src.zip` archive in the root directory of your installation. The Application Programming Interface (API) is described in the html documentation, which accompanies the software (in the `/javadoc` directory).

1.7 Computer resource considerations

The time required to execute an EVS project, as well as the amount of RAM and hard-disk space required, will depend on a wide range of factors, including:

- The number of forecast locations;
- The number of paired forecasts and observations for each location, which itself depends on the forecast frequency, the forecast horizon or number of "lead times", the number of ensemble members etc;

2. Release notes

2.1 Changes from EVS 3.0 (build 10/01/10) to EVS 4.0 (build 10/07/11)

2.1.1 Feature upgrades and modifications not related to Graphical User's Interface

- Added the facility to manually specify the date formats used in the ASCII observed and forecast files. A date format is based on the elementary components, yyyy (year), MM (calendar month), dd (day of month), HH (hour of day in the 24-hour clock), mm (minute of hour) and ss (second of minute). The elements are separated with single characters or whitespace (e.g. MM/dd/yyyy HH) or appended without separators (e.g. yyyyMMddHH). The default date format is MM/dd/yyyy HH.
- Added the relative mean error (RME) to the set of deterministic metrics available in the EVS. The RME comprises the mean error as a fraction of the mean observed value over the sample.
- Added an additional method for computing the Area Under the Curve (AUC) for the empirical Relative Operating Characteristic (ROC) Score. The default method remains the algorithm described in Mason and Graham (2002): Mason, S.J. and Graham N.E., 2002: Areas beneath the relative operating characteristics (ROC) and relative operating levels (ROL) curves: Statistical significance and interpretation, *Quarterly Journal of the Royal Meteorological Society*, **30**, 291-303. The alternative involves computing the AUC from the empirical ROC curve, which is based on a finite number of points/classifiers. The integral of the empirical ROC curve (AUC) is computed using the trapezoid rule. In most cases, the algorithm described by Mason and Graham (2002) generates larger values of the AUC (skill) than the integral of the empirical ROC curve.
- Extended the ROC Score to allow for arbitrary reference forecasts, not just sample climatology.
- Added the likelihood-base-rate (LBR) decomposition of the Brier Score into Type-II conditional bias, discrimination and sharpness, and the corresponding decomposition of the Brier Skill Score into relative Type-II conditional bias, relative discrimination and relative sharpness.
- Added options for computing confidence intervals for the verification metrics (except the box plots). One or more confidence intervals may be computed for selected metrics of a Verification Unit and for an Aggregation Unit. The confidence intervals are derived from a stationary block bootstrap of the

verification pairs. In order to account for temporal statistical dependence, the bootstrap resampling applies to contiguous “blocks” of pairs rather than individual pairs. The blocks are parameterized by their mean length and are sampled from a geometric distribution with that parameter. In order to account for spatial dependence (when computing aggregate verification results across several locations), the absolute times of the sampled blocks may be coordinated/fixed across all locations. The bootstrap algorithm is multi-threaded for improved performance on multi-core, multi-processor, machines.

- Provided additional command line options for suppressing the writing of either the graphical or numerical outputs when running the EVS in batch mode. The writing of graphical outputs is suppressed with –g and the writing of numerical outputs is suppressed with –n.
- Provided additional command line options for converting between legacy file formats (NWS Card and NWS CS binary) and a generic ASCII file format used by the EVS. The option –bin2asc in.cs out.fcst converts the NWS CS binary file, in.cs, to the ASCII output file, out.fst. The option –fcard2asc in.fcst out.fcst converts the forecast data in NWS Card file, in.fcst, to the ASCII output file, out.fst. The option –ocard2asc in.obs out.obs converts the observed data in NWS Card file, in.obs, to the ASCII output file, out.obs.
- Improved the R utilities script for reading the XML numerical outputs from the EVS into R (www.r-project.org). The utilities script is located in /evs/resources/rscripts/Utilities.R. There are three key methods for reading the different EVS outputs, namely readEVSScores, which reads the verification scores, readEVSDiagrams, which reads the verification diagrams (e.g. reliability diagram, spread-bias diagram) and readEVSBoxPlots, which reads the EVS box plots.
- Provided two self-contained R scripts in /evs/resources/rscripts/example_scripts to demonstrate the plotting of EVS output in R. The necessary EVS (XML) outputs are located in evs/resources/rscripts/example_scripts/example_evs_out.
- Added an option to omit ‘no-data’ values from the paired files.

2.1.2 Changes in default behavior

- The observed and forecast file types must now be explicitly defined. This avoids ambiguities and performance issues that can arise from auto-detecting the file types (by opening and reading in the first few bytes in the file and checking against expected types). The default data types are ASCII. Thus, old project files for which paired data are no longer available will encounter an I/O error message if the file types are not ASCII (requiring the types to be explicitly defined for the first time).

- Changed the metric type of the ROC Score from a test of the “Ensemble distribution” to a test of “Ensemble skill.” Arbitrary reference forecasts are now supported for the ROC Score, not just sample climatology.

2.1.3 Feature upgrades and modifications for developers

- Abstracted control of metric calculation by lead time from the individual metrics to a new method in the evs.metric.metrics package, namely computeByLeadTime. This leads to much cleaner and more extensible code. For example, it is no longer necessary to iterate through lead-times when implementing the compute method of a new metric. Rather, the compute method is now generic for the given input data. There are several downstream effects of these changes that have led to significantly better performance, particularly when computing bootstrap confidence intervals (i.e. repeatedly calculating the metrics).

2.1.4 Bug fixes (except for Graphical User's Interface)

- Corrected the importing of NWS Card files to account for several forecast issue times within one day. Previously, the issue date was represented by the year, month, and day of month, but not the hour of day. This led to the duplication (and subsequent elimination) of verification pairs that were assumed, incorrectly, to originate from the same hour of the day.
- Fixed several bugs in the reading of PI-XML files, including the failure to read observations in PI-XML format.
- Fixed several minor bugs identified by FindBugs: http://findbugs.sourceforge.net/

2.1.5 Feature upgrades and modifications related to Graphical User's Interface

- Added the facility to specify the observed and forecast file types in the first verification window, via drop-down menus.
- Added the option to manually specify the date formats for ASCII observed and forecast files. These options appear in the “Other options” pane of the “Additional

options” dialog. The “Additional options” dialog is accessed using the “More” button associated with the input data (2b) in the first window of the “Verification” stage.

- Added an option to specify the number of decimal places for writing verification pairs (the default is 5). This option appears in the “Other options” pane of the “Additional options” dialog. The “Additional options” dialog is accessed using the “More” button associated with the input data (2b) in the first window of the “Verification” stage.
- Added an option to use all observations when computing the sample climatology corresponding to real-valued thresholds. This option appears in the “Other options” pane of the “Additional options” dialog. The “Additional options” dialog is accessed using the “More” button associated with the input data (2b) in the first window of the “Verification” stage.
- Added an option to suppress the writing of conditional pairs via the GUI. Previously, this option was available in the project file only. It is now accessed using the “More” button associated with the output data (2d) in the first window of the “Verification” stage.
- Added the RME and associated explanation and parameter options to the second window of the “Verification” stage.
- Added an option to apply the thresholds defined for a selected verification metric to all other metrics associated with the current Verification Unit. The IDs and status of the thresholds as “Main” (i.e. thresholds for display) are also copied. When copying thresholds that comprise an unconditional constraint (i.e. use of “All data”), the unconditional threshold is only copied to metrics that are based on discrete events. The feature is accessed via the “Do all” button under the basic parameter options (3c) in the second window of the “Verification” stage (after selecting a metric that comprises thresholds as a basic parameter option).
- Reorganized and improved the display of additional parameter options for the verification metrics. These are accessed via the “More” button from the basic parameter options (3c) in the second window of the “Verification” stage.
- Added options relating to the calculation of confidence intervals for the verification metrics. These include specifying one or more intervals in the range [0,1], together with the parameters of the stationary block bootstrap algorithm. These options are included in a separate tabbed pane (labeled “Confidence intervals”) under the advanced parameter options for a particular metric. The advanced parameter options are accessed via the “More” button from the basic

parameter options (3c) in the second window of the “Verification” stage. Additional options apply to the calculation of confidence intervals for Aggregation Units. These options are accessible via the “More” button, which is located adjacent to the tabulated list of Verification Units (2b) in the “Aggregation” stage. The options include omitting the calculation of confidence intervals for the Aggregation Unit (regardless of whether they are required for particular Verification Units) and specifying whether the component Verification Units are statistically dependent.

- Added the option to pool verification pairs across several forecast locations and to compute the verification metrics from the pooled pairs, rather than averaging the metrics from the individual locations. Previously, this option was only accessible via the XML project file. It is now accessible via the “More” button, which is located adjacent to the tabulated list of Verification Units (2b) in the “Aggregation” stage.
- Added shortcuts for selecting particular combinations of metrics in the products table (1b) of the “Output” stage. These options are accessed by right-clicking on the products table. New options include the ability to select all forecast lead times for the selected metrics across all Verification Units (e.g. to output results for the correlation coefficient across several Verification Units).
- Improved the error handling and reporting code, providing more specific and detailed error messages.

2.1.6 Bug fixes related to Graphical User’s Interface

- Corrected several broken hyperlinks in the html descriptions of the verification metrics, which are displayed in the second window of the “Verification” stage.
- Fixed a bug whereby the internal hyperlinks between the descriptions of the EVS verification metrics (i.e. from one html description to another) were not accessible. This was due to the packaging of these html descriptions within a single executable JAR file. In order for the internal links to work properly, a separate directory containing the html descriptions (outside of the executable JAR file) is required, and is now provided with the distribution, namely /evs/resources/statsexplained. The consequences of moving the executable JAR or not downloading this separate directory are minor (i.e. the internal hyperlinks will not work, and navigation to the appropriate description must be performed

manually). However, an error message is now provided in that case, indicating that the html resource cannot be found locally.

2.2 Changes from EVS_2.0 (build 10/01/09) to EVS_3.0 (build 10/01/10)

2.2.1 Feature upgrades and modifications not related to Graphical User's Interface

- Packaged the EVS into a single executable JAR file with all associated libraries using an ANT build script. The EVS is now delivered as a single executable JAR file, without the need to maintain an internal directory structure for dependent libraries (which are now packaged and accessed from within the executable JAR).
- The writing of conditional pairs (i.e. a subset of the overall pairs with any conditions on variable value or date applied) has been made optional to speed-up the processing of large numbers of verification points. This option is implemented via the <write_conditional_pairs> tag of the <paired_data> section of the EVS project file, with a default of true, i.e. conditional pairs are written by default, as before. This option is also accessible via the GUI (see below).
- Improved the performance of the temporal aggregation routine and provided options for the type of aggregation function applied not only to the forecast data, but to the forecast valid times and lead times. Also changed the default behavior; previously, the forecast valid time was given the mean of the input times and the lead time assumed the maximum of the input times; the forecast valid time now assumes the maximum of the input times (see below).
- Improved information and error messages printed to standard out (i.e. the console, if EVS was initiated from a console window).
- Added options for aggregating the support of the observed data to match the support of the forecasts, including the ability to compute an accumulation over a forecast window. Eventually, an aggregation function will be implemented for every possible combination of input support allowed in the EVS (including a change of measurement units).
- Added methods for reading paired data in the same ASCII format to which the XML pairs can be converted. Thus, paired files may be produced and read in ASCII format (as well as forecasts and observations) where convenient.
- Implemented additional R scripts for plotting the verification results produced by the EVS (i.e. the XML output), including a script that will plot the EVS single-valued metrics and ensemble scores as a function of threshold value.

- Implemented the three-part decomposition of the Brier Score into: Brier Score = reliability – resolution + uncertainty and the associated graphical and numerical products.
- Implemented additional options for averaging the forecast ensemble members when computing single-valued verification metrics such as the mean error, root mean square error, mean absolute error, and correlation coefficient. The default remains to compute the ensemble mean. Additional options now include the ensemble median and mode.
- Added the Mean Absolute Error of the ensemble average to the single-valued verification metrics.
- Added the climatological frequency and the zero-skill line to the reliability diagram (located half-way between the climatological frequency and the expected frequency for a reliable forecasting system). These curves are available in the XML output files, but are not plotted within the EVS.
- Backwards compatibility has been maintained for earlier project files. Upon saving old project files within a new version of EVS, new options will be written with their default values.
- Implemented the concept of “main” and “auxiliary” thresholds for metrics that either require or support thresholds. Currently, the “main” thresholds are used to identify events (or subsets of data) that should be included in the graphical outputs from the EVS. By default, both the “main” and “auxiliary” thresholds are included in the numerical outputs from the EVS. This information is stored as an additional XML tag in the project file, labeled main_threshold, which contains a list of Boolean values equal in length to the number of thresholds (true indicates a main threshold).
- Added the facility to derive climatological probability thresholds from a larger set of observed data. In the EVS Version 2.0 they were derived from the paired observations, after applying any requested changes in units, temporal aggregation, or value and date conditions, including the discrete verification time-period requested in the first verification window. Now, they may be derived from the original observed data, again after applying any requested changes in units, temporal aggregation, or date and (observed) value conditions, but NOT the discrete verification time-period (i.e. the full period of record covered by the observed file will be used, after applying any changes in measurement units, temporal aggregation, value conditions on the observations, and date conditions *except* for the reduced verification time period). This option is controlled by a

Boolean flag, which is accessible via a check box in the GUI, and also in the project file under the new XML tag, labeled use_all_observations_for_climatology. Note that this option only applies to the derivation of real-valued thresholds corresponding to particular climatological probabilities of occurrence. For those metrics that incorporate climatological probabilities in the calculation (e.g. the climatological frequency in the reliability diagram), the behavior is unchanged (the observations associated with the conditional pairs are still used).

- Added further date and value (pre-)conditions, including additional statistics for selecting forecasts based on value (ensemble median and mode, probability of not exceeding a given value, and the value corresponding to a given non-exceedence probability) and additional functions for selecting forecasts and observations based on dates (hours of day in UTC). Thus, much more complex pre-conditions are now possible, such as selecting only those pairs (for verification) whose forecast probability of exceeding "flood stage" is greater than 0.9. This functionality is necessary for real-time verification, where the aim is to select historical (observed and forecast) analogs to a real-time forecast based on specific properties of that real-time forecast, and possibly auxiliary information.
- Added the facility to compute the binormal approximation to the Relative Operating Characteristic (ROC) curve and the associated ROC Score. The approximation is based on fitting the binormal model to the empirical (POD, POFD) pairs and is, therefore, dependent on the number of thresholds chosen. For an exact comparison between the binormal approximation to the ROC curve and the binormal approximation to the ROC Score, a common number of thresholds should be adopted for each metric. However, when comparing the empirical ROC Score to the binormal ROC Score, the results will be closest when adopting m+1 thresholds, where m is the number of ensemble members per forecast. Specifically, the empirical ROC Score is derived from ranking of the POD and POFD data, rather than computing the ROC curve. The ranked data can take at most m, "jumps" in probability (at the corresponding ensemble member positions). Hence, the empirical ROC Score is analogous to deriving the ROC Score from an empirical ROC curve constructed with m+1 thresholds.
- Added the facility to aggregate the observed support prior to verification. Previously, this was only possible for the forecasts. The same restrictions apply to change of support of the observations as the forecasts, namely the aggregated support is exactly divisible by the frequency of the data and comprises either a

mean of the input values if the inputs have instantaneous support or a total of the input values if the input values are totals.

- Added the option to remove certain lead times from the verification results based on a minimum sample-size requirement. The sample size constraint is set by a fraction in the range [0,1]. The fraction is multiplied by the average number of pairs across all lead times to determine the minimum sample size in numbers of pairs. For example, a fraction of 0.5 implies that verification results will *not* be computed for any lead time with fewer than 50% of the average number of pairs across all lead times.

The following new features are only accessible via the EVS project file (not the GUI):

- Added the facility to specify the method for computing CRPS in the EVS project file. By default the Hersbach (2000) method is used, but a method that can handle null ensemble members has been added. This is specified in the <crps_method> tag of the crps metric in the EVS project file, with options hersbach and with_nulls. If null members are present, the hersbach option will lead to all forecasts with one or more null members being removed from the calculation, and will fail to compute if all forecasts contain one or more null members.
- The facility to prevent elimination of duplicate pairs (pairs with a common forecast valid time and lead time) has been added to the EVS project file. This is implemented via the <eliminate_duplicates> tag of the <paired_data> section of the EVS project file, with a default value of true. When false, duplicate pairs will not be eliminated. This is necessary when computing verification metrics for data that have been pre-pooled across several forecast locations and contained in a *single* paired file.
- Added an option to pool the verification pairs across several forecast locations and to compute the verification metrics from the pooled pairs, rather than averaging the metrics from the individual locations. Theoretically, this approach is preferred, but is much more time-consuming in practice, and is usually not feasible. The default behavior remains to average the verification metrics from the individual locations. The new option is only accessible via the EVS project file by adding or setting the <pool_pairs>true</pool_pairs> entry to the XML for a particular aggregation unit, where true implies that pooling will be conducted, and false implies averaging.

- Added the facility to change the decimal writing precision of the paired data for a given Verification Unit. This applies to both the raw and conditional pairs. The default behavior is to write forecasts and observations with a maximum precision of five decimal places (unchanged), with fewer places written as required. The integer number of decimal places (>0) can now be defined in the project file using the <paired_write_precision>5</paired_write_precision> tag, which is part of the <paired_data> block. This functionality is not accessible via the GUI, and existing pairs will not be re-written with a new decimal precision (unless re-writing is otherwise necessary).
- Added the facility to set the behavior for removing null ensemble members when writing the paired file. The default behavior remains to *remove* null ensemble members. This may be changed using the <strip_nulls_from_paired_file>true</strip_nulls_from_paired_file> tag, which is part of the <paired_data> block. This functionality is not accessible via the GUI, and existing pairs will not be re-written (unless otherwise required).

2.2.2 Changes in default behavior

- Changed the temporal aggregation default to store the maximum valid time of the input times (in UTC) when conducting aggregation. Previously, the default was to compute the mean of the input times. The default for handling the forecast lead times remains to compute the maximum of the inputs. Thus, for example, aggregation of four six-hourly pairs at increasing UTC times of {18, 0, 6, 12} previously generated an aggregated paired value with time UTC 3, but will now generate an aggregated paired value with time UTC 12 (note that 12 proceeds 18 when considering date). Thus, the aggregated value should be interpreted as the value over the period of aggregation immediately preceding the stated time.
- Changed the start and end dates of the verification period defined in the first verification window from the forecast time zone to UTC. The start and end dates begin and end at 00 UTC on the specified date, respectively. Thus, in order to include verification pairs that fall on the specified end day, one day should be added to the input date.
- Changed the order of error messages displayed in the GUI Console window (not to be confused with an external console) so that the latest error messages are displayed at the top of the console rather than appended to the bottom.

2.2.3 Feature upgrades and modifications for developers

- Added numerous additional methods for developers that assist in sub-setting paired data according to varied conditions met in particular rows or columns of the paired-data matrix. These methods can be found in evs.utilities.matrix.DoubleMatrix2D. The conditions can be made arbitrarily complex by chaining together functions provided in the evs.utilities.mathutil package and applying them to specified rows and/or columns in the paired data matrix.
- Added a method to linearly interpolate observed data to the nearest forecast valid time using a weighed (by temporal separation) combination of the two nearest observations between which the forecast valid time lies. The method is: evs.data.PairedData.linInterpObsToFcsts. This functionality is currently only accessible to developers, but may be included in the GUI in future.
- Enhanced the processing of timing information by adding a dedicated class for representing forecast valid times and lead times: evs.data.ValidTime.

2.2.4 Bug fixes (except for Graphical User's Interface)

- Fixed a bug in the BSS and CRPSS to write the null value identifier where the output of the BSS or CRPSS is undefined (i.e. divide by zero), thereby allowing proper display in the plots for those lead times where the score *is* defined.
- Fixed a bug in the reading of an XML paired file where one or more ensemble members were missing, i.e. the number of members in the paired file (which does not store missing members) varied. The result of this bug was that missing members were initialized with the java default value for a float, namely 0.0, and not the pre-defined null value identifier.
- Fixed a bug in the skill score calculations (BSS and CRPSS). When these calculations were performed repeatedly (i.e. by clicking “Run” two or more times), the skill scores were zeroed on the second or further runs. While the metrics would not normally be re-computed, the bug has been fixed.
- Fixed a bug in the application of value conditions, whereby the conditions were being applied *before* any requested changes in measurement units rather than *after*. The value conditions (and hence real-valued thresholds on which those conditions are based) are now in the target measurement units.

- Fixed a bug in a method for ordering the paired data by trace, whereby the last trace (in order of forecast valid time) was not being appended to the results and, therefore, included in the verification results.
- Spell-checked all developer documentation and corrected spelling mistakes.

2.2.5 Feature upgrades and modifications related to Graphical User's Interface

- Simplified the behavior of the reference forecast selection for skill scores. If a skill score is selected and only one possible reference forecast is available, this is automatically selected in the secondary parameters dialog.
- Added a menu to the Verification Units table in the Output window to allow for the (de)selection of all products and lead times for all available units.
- Added advanced options for computing different averages from the ensemble members when using single-valued verification metrics.
- Added auto-recall of the last directory accessed when creating, saving and reading project files so that the last working directory is opened by default.
- Added an option to change the behavior for writing conditional pairs. This is controlled by a check button in the advanced options (accessed via the “More” button) in the “Output” section of the first window in the GUI. The default (slower) behavior is to write conditional pairs.
- Added support for multiple-row selection and deletion in the thresholds table associated with each verification metric (in the second verification window).
- Added the facility to distinguish between “main” and “auxiliary” thresholds for metrics that either require or support thresholds. By default, the “main” thresholds are used for plotting and all thresholds (“main” and “auxiliary”) are added to any numerical outputs written by the EVS.
- Added functionality to generate verification thresholds semi-automatically for verification metrics that either require or support thresholds. The thresholds are generated by entering a number of thresholds, the first threshold value, and a constant increment (positive or negative) between thresholds. This is useful for designing plots that show verification scores as a ‘continuous’ function of threshold value (i.e. outside of the EVS). By default, only those thresholds identified as “main” thresholds are included in the graphical outputs from the EVS, but the numerical outputs (on which custom plots are designed) include all of the thresholds.

- Re-labeled the “Edit no-data value” option in the advanced input data options dialog to the more generic “Edit other options” and added a check box to control the way observed data are used to determine climatological probability thresholds.
- Improved the GUI for selecting pre-conditions to apply to the verification pairs, in keeping with the enhanced functionality for identifying pre-conditions (see above).
- Added option to iconify (or “minimize” in Windows terminology) the EVS GUI while processing a verification project; a button labeled “iconify” has been added to the progress dialog to facilitate this.
- Changed the label Forecast lead period to Forecast lead time horizon in the first window of the GUI.
- Added the binormal approximation to the ROC and ROC Score to the GUI. In both cases, the binormal approximation is appended to the results when selecting to do so under the Advanced Parameter Options dialog. In that case, the empirical ROC data are plotted as open points and the binormal approximation is plotted with a line of the same color.
- Removed the text (in forecast time system) for both the start and end dates of the verification period in the first window of the GUI, reflecting the change to UTC (see above).
- Added an error message when attempting to temporally aggregate forecasts over a longer period than the specified forecast lead time horizon (e.g. attempting to compute monthly averages for forecasts with a lead time horizon of 14 days).
- Improved the error console in the GUI.

2.2.6 Bug fixes related to Graphical User's Interface

- Fixed a bug in the table of thresholds for each verification metric, ensuring that the scrolling window expands properly as new thresholds are added (previously a fixed limit).
- Fixed a bug in the table of candidate units for aggregation, ensuring that the scrolling window expands properly to show all available units (previously a fixed limit).
- Corrected a bug in the GUI for selecting pre-conditions to apply to the verification pairs. Entering incorrect conditions lead to a (correct) warning, but, when subsequently cancelling further edits, the existing (valid) conditions were removed rather than being returned to the original (valid) state.

2.3 Changes from EVS 1.0 (build 05/09/08) to EVS 2.0 (build 10/12/09)

2.3.1 Feature upgrades and modifications not related to Graphical User's Interface

- Added multiplication factor in support dialog to allow simple changes between measurement units (more complex operations, such as a change in temperature units, are not yet supported).
- Implemented reading of PI-XML observations
- Implemented reading of PI-XML forecasts
- Implemented reading of ASCII observations
- Implemented reading of ASCII forecasts
- Changed representation of forecast lead times from integer hours to double-precision float hours to allow verification of forecasts with lead times in fractional hours, thereby extending the EVS to arbitrary forecast lead times.
- Rewrote the online documentation and updated the mathematical formulas for all of the verification metrics.
- Implemented an R script for each metric in the EVS to read in the XML output and produce high quality plots in EPS format for scientific papers.
- Modified calculation of the mean CRPS to account for the relative position of the observation between the two adjacent ensemble members.
- Added ROC score to the available metrics and included a plot by forecast lead time (same as with other scores). The calculation is based on Mason and Graham (2000).
- Added a sample size metric and associated plot to compute the basic sample size information by forecast lead time and threshold. This may be used for exploratory purposes before computing other verification metrics. In future, we may add further metrics for data exploration (of the observed and forecast data rather than the verification pairs).
- Added modified box plot by size of observed value to GUI (previously via the command line only).
- Modified the spatial aggregation routine to compute the expected (mean) value of each metric across a set of Verification Units rather than pooling paired data.
- Included ability to perform a weighted spatial aggregation. The weight is uniform by default and must sum to 1. A non-uniform weight is also permissible and a weight of "S" is used to weight by the sample size at the first lead time (i.e. maintaining constant weights across lead times). If a verification metric is not

available for a given lead time or threshold the weights are automatically rescaled to sum to 1, maintaining the correct relative weighting of the available metrics.

- Relaxed constraints on spatial aggregation to allow aggregation for Verification Units with different start and end dates.
- Improved the efficiency of file reading for external file formats to ensure that only data within the specified start and end dates and forecast lead times are fully read (otherwise only the file headers are read to check this information).
- Implemented backwards compatibility for the above features so that they do not prevent running of old EVS projects. However, the aggregation routine and CRPS update has been swapped without the option of backwards compatibility. Thus, old projects with spatial aggregation will produce different results in the EVS 2.0. The CRPS update was a bug fix, voiding the need for backwards compatibility.
- Updated the algorithm for CRPS to the method described in Hersbach, H., 2000: Decomposition of the Continuous Ranked Probability Score for Ensemble Prediction Systems. There are small numerical differences between the old and new algorithms. Also, the procedure described in Hersbach assumes that a constant number of ensemble members is available, whereas the previous method for computing CRPS had no such constraint. Thus, differences will be seen when comparing numbers between systems for which some forecasts comprise null ensemble members.
- Added the decomposition of the CRPS into reliability, resolution and uncertainty, as described in Hersbach (2000).
- Added the Brier Skill Score (BSS) for an arbitrary reference forecast selected by the user.
- Added the Continuous Ranked Probability Skill Score (CRPSS) for an arbitrary reference forecast selected by the user.

2.3.2 Feature upgrades and modifications related to Graphical User's Interface

- Removed Time-Series ID and renamed River Segment ID to Location ID.
- Moved basic output options from pop-up window to main Output window.
- Implemented enhanced error dialog with improved error messages.
- Implemented enhanced progress monitor to monitor and display progress of paired-file reading (and included a pair count in the paired file to enable this).
- Updated the aggregation window to include a weighting input in the table of verification metrics. Also renamed some features in this window.

- Added the option to select an arbitrary reference forecast for a skill metric.
- Added the option to show skill score decompositions in a tabbed pane (similar to metrics with one plot per lead time), which may be animated.
- Improved display of zero error line in plots (extended continuously).
- Improved auto-scaling of axes in plots.

2.4 Changes from EVS 1.0 BETA (build 10/12/07) to EVS 1.0 (build 05/09/08)

2.4.1 Feature upgrades and modifications not related to Graphical User's Interface)

- Allowed real-valued thresholds for all metrics.
- Allowed probability thresholds for all metrics, not just Brier, ROC, and Reliability.
- Included the option for thresholding with a closed interval (i.e. a "between" condition).
- Supported the use of symmetric windows around the forecast median in the Spread-Bias plot.
- Included sharpness (sample-count) plot in the Reliability diagram.
- Changed the definition of probability thresholds in Spread-Bias plot, Mean Capture Rate diagram and Box Plots. Previously, these thresholds referred to plotting positions (i.e. plot resolution) and NOT thresholds of the observed distribution. They now refer to thresholds of the observed distribution for consistency with all other metrics. Plotting positions are now determined with a 'points count' parameter. For example, a point count of 10 for the Spread-Bias plot will construct a plot comprising 10 points.
- Added a new 'points count' parameter for the Spread-Bias plot, Mean Capture Rate diagram, Box Plots and Reliability diagram, which allows the resolution of those diagrams to be altered.
- Included the option to change the default temporal aggregation function from the mean over a specified period to one of several other functions, including the minimum, maximum, and total (i.e. accumulation).
- Included units in the plots that comprise real units (mean error, RMSE, Mean Capture Rate diagram, box plots) once those units have been added to the observed and forecast support for a Verification Unit.
- Included an option to animate a sequence of verification graphics at different lead times.

- Included writing of sample counts to an XML file when writing other numerical results.
- Included writing of conditional pairs to XML format as well as the original pairs.
- Included an option to ignore global value conditions on a per-metric basis. For example, if a condition was applied to consider only those pairs whose ensemble mean temperatures exceeded freezing, this condition could be ignored on a per-metric basis.
- Enabled backwards compatibility with old project files (i.e. projects with old options will run as before).
- Enhanced and updated documentation.
- Improved memory management for Aggregation units.

2.4.2 Feature upgrades and modifications related to Graphical User's Interface)

- Removed the table containing reference forecasts, which are not yet enabled.
- Improved the labeling of various options (e.g. 'time zones' rather than 'time systems').